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THE USE OF THE ELECTROLYTIC BRIDGE FOR DETERMINING SOLUBLE SALTS

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THE MODIFIED WHEATSTONE BRIDGE

The modified Wheatstone bridge, as developed in the soil physics laboratory [1] of the Bureau of Soils, for the determination of soluble salts in soils or in water, has proved one of the most useful instruments of its kind. Its greatest utility is in determining the quantity of alkali or the harmful excess of soluble salts in the soils of the arid or semiarid regions. It is useful not only in the study of soils, but also in the determination of quantities of soluble salts present in drainage and irrigation waters. It also has uses in the laboratory in the study of soil solutions or other electrolytes. Although the method is not accurate and gives only an approximation of the quantity of soluble salts present, it is nevertheless very useful for rapid work in both field and laboratory.

The instrument is a modified form of the Wheatstone bridge. It is inclosed in a substantial wooden box and consists of a slide wire on a circular disk, a small induction coil, a battery, resistances, telephone receiver, and a cup to hold the soil material or solution to be tested. The box has two compartments, an upper and a lower, hinged together and supplied with a hinged cover. The lower com-

[1] BRIGGS, L. J. ELECTRICAL INSTRUMENTS FOR DETERMINING THE MOISTURE, TEMPERATURE, AND SOLUBLE SALT CONTENT OF SOILS. U. S. Dept. Agr., Div. Soils, Bul. 15, 35 p., illus. 1899.
DAVIS, R. O. E., and BRYAN, H. THE ELECTRICAL BRIDGE FOR THE DETERMINATION OF SOLUBLE SALTS IN SOILS. U. S. Dept. Agr., Bur. Soils, Bul. 61, 36 p. illus. 1910.
WHITNEY, M., and MEANS, T. H. AN ELECTRICAL METHOD OF DETERMINING THE SOLUBLE SALT CONTENT OF SOILS. U. S. Dept. Agr., Div. Soils, Bul. 8, 30 p. illus. 1897.

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partment contains the battery, the induction coil, and the cup. On the underside of the upper compartment is the disk carrying the slide wire, and the resistances. In the upper compartment are the scale, the plunger and pointer for obtaining a balance, the cup holder, resistance switches, and the telephone receiver.

A diagram showing the interior connections and wiring of the bridge is shown in Figure 1. The cup containing the material whose resistance is to be measured is the variable resistance in one arm of the bridge, and the comparison coils, made up of three fixed resistances of 10, 100, and 1,000 ohms, are in the other arm of the bridge. Either of the fixed coils may be used by operating the rotary switch with which they are connected. There is a 100-ohm

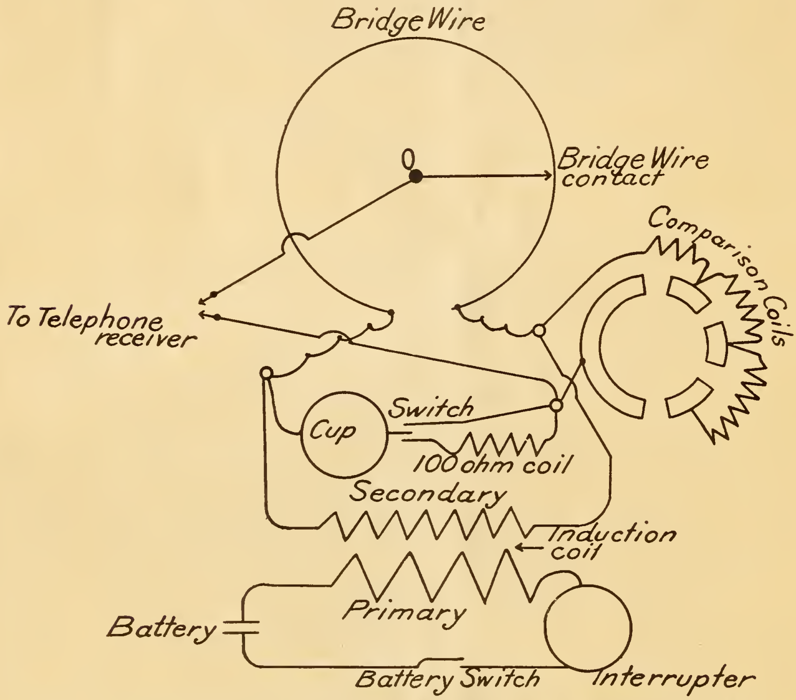

FIG. 1.—Diagram showing the interior connections of the electrolytic bridge

coil that may be connected in series with the cup when the resistance of the cup is low. The current passing is an interrupted current from the secondary coil of an induction coil. An ordinary dry cell furnishes current for the primary coil. By locating a point on the slide wire where the sound in the telephone ceases, a balance is established between the two segments of the slide wire and the fixed and variable resistances. Since a simple proportion obtains between these values and all are known but one, it is an easy matter to determine that one. The scale on the slide wire is so graduated that its reading multiplied by the resistance of the comparison coil gives the resistance of the cup contents. The general appearance and arrangement of the field instrument are shown in Figures 2 and 3.

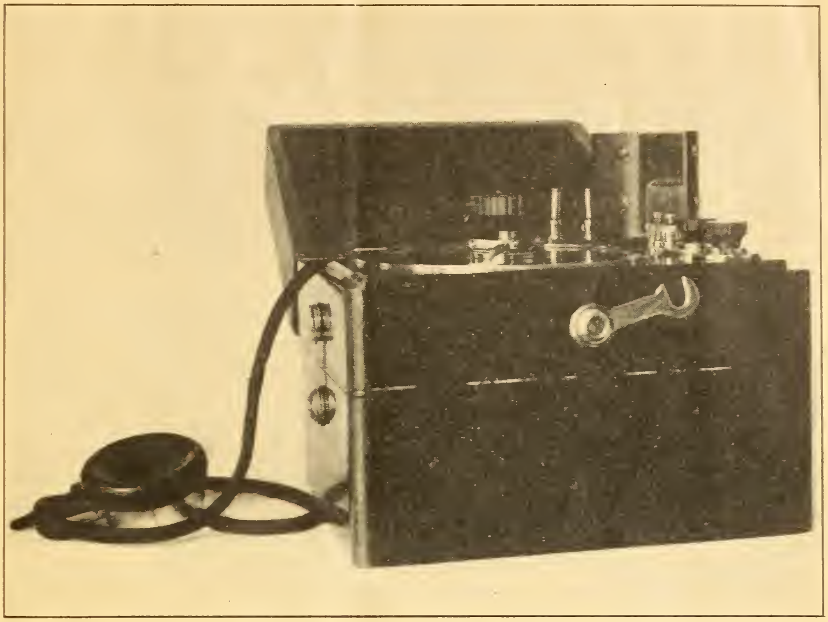

FIG. 2.—Bridge box with cover raised, showing cup in position ready for use

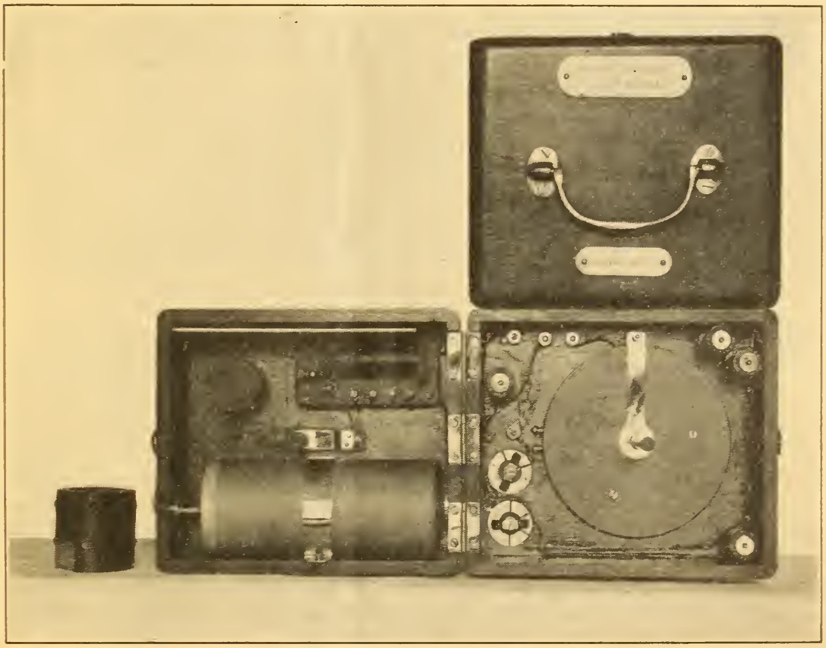

FIG. 3.—Bridge box open, showing interior

METHOD OF OPERATION

The use of the bridge involves the determination of the electrical resistance in ohms at 60° F. of the contents of a cup of fixed capacity filled with either soil material or a solution. The resistance increases with the decrease in quantity of salt present. The change of resistance with a change in concentration of any solution may be represented by a curve, using resistance and concentration as coordinates. Such a curve, constructed by observing the resistances corresponding to various concentrations of a salt solution, may constitute a standardization curve by aid of which the approximate concentration of similar salt solutions may be determined from the resistance readings.

The soil material or solution, the salt content of which is to be determined, is put into the hard-rubber cup with metal electrodes. The cup should be level full and free from air bubbles when the measurement of the electrical resistance is made. To determine the salt content of a soil, the soil material to be tested should be thoroughly mixed with distilled water until the saturation point is reached, as indicated by the appearance of free water. If distilled water is not available, rain water, or water as free from soluble salts as possible, should be used. The accuracy of the results depends on the absence of dissolved salts in the water used. This saturated soil material is transferred to the cup with a spatula, the bottom of the cup being tapped at the same time to expel air bubbles. The filled cup is slipped into the spring contacts on the bridge, and the electrical resistance of the contents is then determined as follows: The telephone receiver of the instrument is placed against the ear, and the plunger carrying the pointer is pressed down. A buzzing sound should be heard. Holding the plunger down, rotate the pointer back and forth until a position is determined at which the sound in the telephone disappears or is reduced to a minimum. If a balance is not obtained with the 10-ohm resistance coil, then the 100-ohm and the 1,000-ohm coils must be tried in turn. If the 10-ohm coil gives a minimum sound but the exact position is not determinable, the 100-ohm comparison coil may be thrown to the " in " position. In such a case the 100 ohms must be deducted from the resistance reading to determine the resistance of the cup contents. The resistance coil which gives the minimum sound nearest the center of the scale is the most satisfactory.

The resistance of the cup contents is found by multiplying the reading of the resistance coil used on the rotary switch by the number on the scale opposite the pointer when an equilibrium is established. For example, if the 100-ohm resistance coil is used and the scale reading is 0.92, the resistance of the contents of the cup is 92 ohms. The resistance of the cup contents must be corrected to a temperature of 60° F. To do this, immediately after a reading is taken a thermometer is inserted in the cup contents and read after two minutes. The resistance at the temperature found is then corrected to 60°, according to Table 1. When the resistance of the cup contents at 60° has been found, the percentage of soluble material in soils which contain sulphates and chlorides is determined by the

use of Tables 2 and 3, and the percentage of soluble material in those containing carbonates by the use of Tables 4 and 5.

LIMITATIONS

The field instrument as designed in the Bureau of Soils is not intended as an instrument of precision. However, if the character of the salts with which one is dealing is known, the measurements with the bridge give a fairly close approximation to the total quantity of soluble salts present. In addition, it must be strongly emphasized that where any doubts exist as to the accuracy of the results obtained, a standardization curve should be constructed in the way described on page 10. The great advantage in the use of the instrument is that, after the standard curve has been obtained, any number of determinations may be made with the bridge, so long as the same kinds of salts are present.

The presence of carbonates and organic matter in the soil materials or solution ordinarily causes the widest variation from the figures given in Tables 1 and 2, and when the quantity of organic matter is large, the results are not reliable. The errors that ordinarily occur, however, are of such a character that the usefulness of the bridge is not impaired in determining approximately the soluble or alkali salts in the soil, or the soluble material in drainage, irrigation, or boiler waters.

CARE OF THE BRIDGE

Although the bridge is designed for field use, it is a delicate instrument and should not be subjected to rough usage. If it is subjected to knocks or jars the connections may be broken, the balancing mechanism may be injured, or parts may be jostled out of place. The accumulation of dust on some of its parts may be injurious; dust on the bridge wire may prevent proper connection of the sliding contact, or dust on the interrupter of the induction coil may interfere with its operation. These parts should be wiped occasionally with a soft cloth, and the contacts of the switches should be kept clean and bright. When any soldered connections are broken, they should be repaired by somebody who is familiar with the construction of the bridge.

TESTING THE BRIDGE

A heavy metal piece, which fits between the cup clips, is supplied for the purpose of testing the bridge. The 100-ohm coil is placed in the circuit with the switch thrown to the "in" position. This 100-ohm resistance should be balanced by the 100-ohm resistance in the other arm of the bridge; that is, the minimum sound in the telephone receiver should occur when the pointer is at 1.0 on the scale. If the reading differs slightly the proper corrections should be made by setting the pointer at the correct point. If the minimum sound occurs at a considerable distance from the 1.0 point on the scale, the instrument is probably out of order.

If reasonable care is exercised, the bridge will seldom develop any trouble, but occasionally it may fail to work for a number of reasons.

If no sound can be heard in the telephone receiver the trouble may be (1) an exhausted battery, (2) lack of contact in the battery switch, owing to dirt on the points, (3) improper adjustment of the current interrupter, (4) broken connections, (5) failure of the contact spring of the balancing mechanism to make connection with the bridge wire, or (6) a faulty telephone receiver.

If the interrupter gives a buzzing sound which can not be heard in the telephone, the trouble can not be in the battery or interrupter. If the interrupter can not be made to function, the connections of the battery and induction coil should be examined. If these connections are good, the battery should be replaced. If no sound is then heard in the telephone, there is a broken connection or the telephone receiver is out of order. If the difficulty seems to be in the bridge wire, the slide should be examined carefully and adjusted, if necessary, to make better contact. A note heard in the receiver for part of the scale only, indicates trouble with the slide-wire contact. If the trouble seems to be in the receiver, the connections inside the bridge box and then the cord terminals should be examined. In case these are satisfactory, the receiver should be tested directly on the battery circuit.

If the trouble is not located in any of the above-mentioned ways it must be inside the coils. In that case the instrument should be placed in the hands of a professional instrument maker or electrician for repairs.

TEMPERATURE CORRECTIONS

Table 1 is supplied to enable one to reduce the resistance readings to 60° F. To illustrate its use, suppose the resistance to be 1,349 ohms at 72° F. On the left-hand side of Table 1 find 72° F.; opposite, under the column marked 1,000, will be found 1,170 ohms at 60°, as the value of 1,000 ohms resistance at 72°. A resistance of 3,000 ohms at 72° will be found to be equivalent to 3,510 at 60°. Hence a resistance of 300 at 72° is equal to 351 at 60°; 40 is equal to 46.8 ohms at 60°; and 9 is equal to 10.5 ohms at 60°. Add these values together, as:

Observed resistance at 72° F.	Equivalent resistance at 60° F.
Ohms	*Ohms*
1,000	1,170.0
300	351.0
40	46.8
9	10.5
At 72° F. 1,349 =	1,578.3 at 60° F.

In a similar manner Table 1 may be used to reduce any resistance to 60° F.

TABLE 1.—*Equivalent electrical resistances in ohms at 60° F. for resistances observed at temperatures below and above 60° F.*

° F.	Resistance at observed temperature								
	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
	Equivalent resistance at 60° F.								
32.0	625	1,250	1,875	2,500	3,125	3,750	4,375	5,000	5,625
32.5	632	1,265	1,897	2,530	3,163	3,795	4,425	5,059	5,691
33.0	640	1,280	1,920	2,560	3,200	3,840	4,480	5,120	5,760
33.5	647	1,294	1,941	2,588	3,235	3,883	4,530	5,177	5,824
34.0	653	1,306	1,959	2,612	3,265	3,918	4,571	5,224	5,877
34.5	660	1,320	1,980	2,640	3,300	3,960	4,620	5,280	5,940
35.0	668	1,336	2,004	2,672	3,340	4,008	4,676	5,344	6,012
35.5	675	1,350	2,025	2,700	3,375	4,050	4,725	5,400	6,075
36.0	683	1,366	2,049	2,732	3,415	4,098	4,781	5,464	6,147
36.5	690	1,380	2,070	2,760	3,450	4,140	4,830	5,520	6,210
37.0	698	1,396	2,094	2,792	3,490	4,188	4,886	5,584	6,282
37.5	704	1,408	2,112	2,816	3,520	4,224	4,928	5,632	6,336
38.0	711	1,422	2,133	2,844	3,555	4,266	4,977	5,688	6,399
38.5	717	1,434	2,151	2,868	3,585	4,302	5,019	5,736	6,453
39.0	723	1,446	2,169	2,892	3,615	4,338	5,061	5,784	6,507
39.5	729	1,458	2,187	2,916	3,645	4,374	5,103	5,832	6,561
40.0	735	1,470	2,205	2,940	3,675	4,410	5,145	5,880	6,615
40.5	742	1,484	2,226	2,968	3,710	4,452	5,194	5,936	6,678
41.0	750	1,500	2,250	3,000	3,750	4,500	5,250	6,000	6,750
41.5	757	1,514	2,271	3,028	3,785	4,542	5,299	6,056	6,813
42.0	763	1,526	2,289	3,052	3,815	4,578	5,341	6,104	6,867
42.5	770	1,540	2,310	3,080	3,850	4,620	5,390	6,160	6,930
43.0	776	1,552	2,328	3,104	3,880	4,656	5,432	6,208	6,984
43.5	782	1,564	2,346	3,128	3,910	4,692	5,474	6,256	7,038
44.0	788	1,576	2,364	3,152	3,940	4,728	5,516	6,304	7,092
44.5	794	1,588	2,382	3,176	3,970	4,764	5,558	6,352	7,146
45.0	800	1,600	2,400	3,200	4,000	4,800	5,600	6,400	7,200
45.5	807	1,614	2,421	3,228	4,035	4,842	5,649	6,456	7,263
46.0	814	1,628	2,442	3,256	4,070	4,884	5,698	6,512	7,326
46.5	821	1,642	2,463	3,284	4,105	4,926	5,747	6,568	7,389
47.0	828	1,656	2,484	3,312	4,140	4,968	5,796	6,624	7,452
47.5	835	1,670	2,505	3,340	4,175	5,010	5,845	6,680	7,515
48.0	843	1,686	2,529	3,372	4,215	5,058	5,901	6,744	7,587
48.5	850	1,700	2,550	3,400	4,250	5,100	5,950	6,800	7,650
49.0	856	1,712	2,568	3,424	4,280	5,136	5,992	6,848	7,704
49.5	862	1,724	2,586	3,448	4,310	5,172	6,034	6,896	7,758
50.0	867	1,734	2,601	3,468	4,335	5,202	6,069	6,936	7,803
50.5	874	1,748	2,622	3,496	4,370	5,244	6,118	6,992	7,866
51.0	881	1,762	2,643	3,524	4,405	5,286	6,167	7,048	7,929
51.5	887	1,774	2,661	3,548	4,435	5,322	6,209	7,096	7,983
52.0	893	1,786	2,679	3,572	4,465	5,358	6,251	7,144	8,037
52.5	900	1,800	2,700	3,600	4,500	5,400	6,300	7,200	8,100
53.0	906	1,812	2,718	3,624	4,530	5,436	6,342	7,248	8,154
53.5	912	1,824	2,736	3,648	4,560	5,472	6,384	7,296	8,208
54.0	917	1,834	2,751	3,668	4,585	5,502	6,419	7,336	8,253
54.5	925	1,850	2,775	3,700	4,625	5,550	6,475	7,400	8,325
55.0	933	1,866	2,799	3,732	4,665	5,598	6,531	7,464	8,397
55.5	940	1,880	2,820	3,760	4,700	5,640	6,580	7,520	8,460
56.0	947	1,894	2,841	3,780	4,735	5,682	6,629	7,576	8,523
56.5	954	1,908	2,862	3,816	4,770	5,724	6,678	7,632	8,586
57.0	961	1,922	2,883	3,844	4,805	5,766	6,727	7,688	8,649
57.5	968	1,936	2,904	3,872	4,839	5,807	6,775	7,743	8,711
58.0	974	1,948	2,922	3,896	4,870	5,844	6,818	7,792	8,766
58.5	981	1,961	2,942	3,923	4,903	5,884	6,864	7,845	8,826
59.0	987	1,974	2,962	3,949	4,936	5,923	6,910	7,898	8,885
59.5	994	1,988	2,982	3,976	4,971	5,965	6,959	7,953	8,947
60.0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
60.5	1,006	2,013	3,019	4,026	5,032	6,039	7,045	8,052	9,059
61.0	1,013	2,026	3,039	4,052	5,065	6,078	7,091	8,104	9,117
61.5	1,020	2,040	3,060	4,080	5,100	6,120	7,140	8,160	9,180
62.0	1,027	2,054	3,081	4,108	5,135	6,162	7,189	8,216	9,243
62.5	1,033	2,067	3,100	4,134	5,167	6,201	7,234	8,268	9,302
63.0	1,040	2,080	3,120	4,160	5,200	6,240	7,280	8,320	9,360
63.5	1,047	2,094	3,141	4,188	5,235	6,282	7,329	8,376	9,423
64.0	1,054	2,108	3,162	4,216	5,270	6,324	7,378	8,432	9,486
64.5	1,060	2,121	3,181	4,242	5,302	6,363	7,423	8,484	9,545
65.0	1,067	2,134	3,201	4,268	5,335	6,402	7,469	8,536	9,603
65.5	1,074	2,148	3,222	4,296	5,370	6,444	7,518	8,592	9,666
66.0	1,081	2,162	3,243	4,324	5,405	6,486	7,567	8,648	9,729
66.5	1,088	2,176	3,264	4,352	5,440	6,528	7,616	8,704	9,792
67.0	1,095	2,190	3,285	4,380	5,475	6,570	7,665	8,760	9,855
67.5	1,102	2,205	3,307	4,410	5,512	6,615	7,717	8,820	9,922
68.0	1,110	2,220	3,330	4,440	5,550	6,660	7,770	8,880	9,990
68.5	1,117	2,235	3,352	4,470	5,587	6,705	7,823	8,940	10,058
69.0	1,125	2,250	3,375	4,500	5,625	6,750	7,875	9,000	10,125
69.5	1,133	2,265	3,398	4,530	5,663	6,795	7,928	9,060	10,193
70.0	1,140	2,280	3,420	4,560	5,700	6,840	7,980	9,120	10,260
70.5	1,147	2,285	3,442	4,590	5,737	6,885	8,032	9,180	10,327
71.0	1,155	2,310	3,465	4,620	5,775	6,930	8,085	9,240	10,395

TABLE 1.—*Equivalent electrical resistances in ohms at 60° F., etc.*—Continued

° F.	Resistance at observed temperature								
	1, 000	2, 000	3, 000	4, 000	5, 000	6, 000	7, 000	8, 000	9, 000
	Equivalent: resistance at 60° F.								
71. 5	1, 162	2, 325	3, 487	4, 650	5, 812	6, 975	8, 137	9, 300	10, 462
72. 0	1, 170	2, 340	3, 510	4, 680	5, 850	7, 020	8, 190	9, 360	10, 530
72. 5	1, 177	2, 355	3, 532	4, 710	5, 887	7, 065	8, 242	9, 420	10, 597
73. 0	1, 185	2, 370	3, 555	4, 740	5, 925	7, 110	8, 295	9, 480	10, 665
73. 5	1, 193	2, 386	3, 579	4, 772	5, 965	7, 158	8, 351	9, 544	10, 737
74. 0	1, 201	2, 402	3, 603	4, 804	6, 005	7, 206	8, 407	9, 608	10, 809
74. 5	1, 208	2, 416	3, 624	4, 832	6, 040	7, 248	8, 456	9, 664	10, 872
75. 0	1, 215	2, 430	3, 645	4, 860	6, 075	7, 290	8, 505	9, 720	10, 935
75. 5	1, 222	2, 445	3, 667	4, 890	6, 112	7, 335	8, 557	9, 780	11, 002
76. 0	1, 230	2, 460	3, 690	4, 920	6, 150	7, 380	8, 610	9, 840	11, 070
76. 5	1, 237	2, 475	3, 712	4, 950	6, 187	7, 425	8, 662	9, 900	11, 137
77. 0	1, 245	2, 490	3, 735	4, 980	6, 225	7, 470	8, 715	9, 960	11, 205
77. 5	1, 253	2, 506	3, 759	5, 012	6, 265	7, 518	8, 771	10, 024	11, 277
78. 0	1, 261	2, 522	3, 783	5, 044	6, 305	7, 566	8, 827	10, 088	11, 349
78. 5	1, 269	2, 538	3, 807	5, 076	6, 345	7, 614	8, 883	10, 152	11, 421
79. 0	1, 277	2, 554	3, 831	5, 108	6, 385	7, 662	8, 939	10, 216	11, 493
79. 5	1, 285	2, 576	3, 856	5, 142	6, 427	7, 713	8, 998	10, 284	11, 569
80. 0	1, 294	2, 598	3, 882	5, 176	6, 470	7, 764	9, 058	10, 352	11, 646
80. 5	1, 302	2, 609	3, 906	5, 208	6, 510	7, 812	9, 114	10, 416	11, 718
81. 0	1, 310	2, 620	3, 930	5, 240	6, 550	7. 860	9, 170	10, 480	11, 790
81. 5	1, 318	2, 637	3, 955	5, 274	6, 592	7, 911	9, 229	10, 546	11, 866
82. 0	1, 327	2, 654	3, 981	5, 308	6, 635	7, 962	9, 289	10, 616	11, 943
82. 5	1, 335	2, 670	4, 005	5, 340	6, 675	8, 010	9, 345	10, 680	12, 015
83. 0	1, 343	2, 686	4, 029	5, 372	6, 715	8, 058	9, 401	10, 744	12, 087
83. 5	1, 351	2, 702	4. 053	5, 404	6, 755	8, 106	9, 457	10, 808	12, 159
84. 0	1, 359	2, 718	4, 077	5, 436	6, 795	8, 154	9, 513	10, 872	12, 231
84. 5	1, 367	2, 735	4, 102	5, 470	6, 837	8, 205	9, 572	10, 940	12, 307
85. 0	1, 376	2, 752	4, 128	5, 504	6, 830	8, 256	9, 632	11, 008	12, 384
85. 5	1, 385	2, 769	4, 153	5, 538	6, 922	8, 307	9, 691	11, 076	12, 460
86. 0	1, 393	2, 786	4, 179	5, 572	6, 965	8, 358	9, 751	11, 144	12, 537
86. 5	1, 401	2, 802	4, 203	5, 604	7, 005	8, 406	9, 807	11, 208	12, 609
87. 0	1, 409	2, 818	4, 227	5, 636	7, 045	8, 454	9, 863	11, 272	12, 681
87. 5	1, 418	2, 836	4, 254	5, 672	7, 090	8, 508	9, 931	11, 344	12, 762
88. 0	1, 427	2, 854	4, 281	5, 708	7, 135	8, 562	9, 989	11, 416	12, 843
88. 5	1, 435	2, 870	4, 305	5, 740	7, 175	8. 610	10, 040	11, 480	12, 915
89. 0	1, 443	2, 886	4, 329	5, 772	7. 215	8, 658	10, 091	11, 544	12, 987
89. 5	1, 451	2. 903	4, 354	5, 806	7, 257	8, 709	10, 155	11, 612	13, 063
90. 0	1, 460	2, 920	4. 380	5, 840	7, 300	8, 760	10, 220	11, 680	13, 140
90. 5	1, 468	2, 937	4, 405	5, 874	7, 342	8, 811	10, 279	11, 748	13, 216
91. 0	1, 477	2, 954	4, 431	5, 908	7, 385	8, 862	10, 339	11, 816	13, 293
91. 5	1, 486	2, 972	4, 458	5, 944	7, 430	8, 916	10, 402	11, 888	13, 374
92. 0	1, 495	2, 990	4, 485	5, 980	7, 475	8, 970	10, 465	11, 960	13, 455
92. 5	1, 504	3, 008	4, 512	6, 016	7, 520	9, 024	10, 528	12, 032	13, 536
93. 0	1, 513	3, 026	4, 539	6, 052	7, 565	9, 078	10, 591	12, 104	13, 617
93. 5	1. 522	3, 035	4, 567	6, 090	7, 612	9, 135	10, 657	12, 180	13, 702
94. 0	1, 532	3, 064	4, 596	6, 128	7, 660	9, 192	10, 724	12, 256	13, 788
94. 5	1, 541	3, 083	4, 624	6. 166	7, 707	9, 249	10, 790	12, 332	13, 873
95. 0	1, 551	3, 102	4. 653	6, 204	7, 755	9, 306	10, 857	12, 408	13, 959
95. 5	1, 560	3, 121	4, 681	6, 242	7, 802	9, 363	10, 923	12, 484	14, 040
96. 0	1, 570	3, 140	4, 710	6, 280	7, 850	9, 420	10, 990	12, 560	14, 130
96. 5	1, 580	3, 160	4, 740	6, 320	7, 900	9, 480	11, 060	12, 640	14, 220
97. 0	1, 590	3, 180	4, 770	6, 360	7, 950	9, 540	11, 130	12, 720	14, 310
97. 5	1, 600	3, 201	4, 801	6, 402	8, 002	9, 603	11, 203	12, 804	14, 404
98. 0	1, 611	3, 222	4, 833	6, 444	8, 055	9, 666	11, 277	12, 888	14, 499
98. 5	1, 620	3, 240	4, 860	6, 480	8, 100	9, 720	11, 340	12, 960	14, 580
99. 0	1, 629	3, 258	4, 887	6, 516	8, 145	9, 774	11, 403	13, 032	14, 661

TABLE 2.—*Resistance of materials containing sulphate and chloride*

Salt content (sulphates and chlorides)	Resistance at 60° F.						Ratio of soil resistance to solution resistance			
	Solution	Sand	Loam	Clay loam	Clay	Average	Sand	Loam	Clay loam	Clay
Per cent	*Ohms*	*Ohms*	*Ohms*	*Ohms*	*Ohms*	*Ohms*				
3. 0	12	17. 8	17. 9	19. 0	21. 0	18. 9	1. 48	1. 49	1. 58	1. 75
1. 0	25	36. 4	37. 9	41. 5	44. 5	40. 1	1. 46	1. 52	1. 66	1. 78
. 6	39	55. 4	57. 6	62. 0	68. 4	60. 9	1. 42	1. 48	1. 59	1. 75
. 4	58	83. 6	86. 8	92. 5	98. 5	90. 4	1. 44	1. 49	1. 60	1. 70
. 2	106	153. 0	158. 9	164. 5	174. 1	162. 6	1. 44	1. 50	1. 57	1. 64
Average							1. 45	1. 50	1. 60	1. 72

TABLE 3.—*Mixed-salt content of soils with given resistance*

Soil resistance at 60° F.	Mixed-salt content of—				Soil resistance at 60° F.	Mixed-salt content of—			
	Sand	Loam	Clay loam	Clay		Sand	Loam	Clay loam	Clay
Ohms	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Ohms*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
18	3.00	3.00	--------	--------	95	0.35	0.37	0.39	0.42
19	2.40	2.64	3.00	--------	100	.33	.35	.37	.39
20	2.20	2.42	2.80	3.00	105	.31	.33	.35	.37
25	1.50	1.70	1.94	2.20	110	.30	.32	.33	.35
30	1.24	1.34	1.46	1.58	115	.28	.29	.31	.33
35	1.04	1.14	1.22	1.32	120	.27	.28	.29	.32
40	.86	.94	1.04	1.14	125	.25	.26	.28	.30
45	.75	.78	.88	.98	130	.24	.25	.26	.28
50	.67	.71	.77	.86	135	.23	.24	.25	.27
55	.60	.64	.69	.77	140	.22	.23	.24	.26
60	.55	.58	.63	.70	145	.21	.22	.23	.25
65	.51	.54	.57	.63	150	.21	.21	.22	.24
70	.48	.50	.53	.59	155	.20	.21	.21	.23
75	.45	.47	.50	.55	160	.20	.20	.21	.22
80	.42	.44	.47	.51	165	.19	.20	.20	.21
85	.39	.42	.44	.48	170	.19	.19	.20	.20
90	.37	.39	.41	.45					

TABLE 4.—*Resistance of materials containing carbonate*

Salt content[1]	Resistance at 60° F.					Ratio of soil resistance to solution resistance			
	Solution	Sand	Loam	Clay loam	Clay	Sand	Loam	Clay loam	Clay
Per cent	*Ohms*	*Ohms*	*Ohms*	*Ohms*	*Ohms*				
3.0	12	23.6	24.6	24.6	30.0	2.00	2.05	2.05	2.50
1.0	24	54.7	68.5	69.4	96.1	2.28	2.86	2.89	4.00
.6	35	82.6	114.8	126.2	152.5	2.36	3.28	3.61	4.36
.4	51	131.6	168.1	201.9	216.2	2.58	3.30	3.96	4.25
.2	94	270.6	312.3	376.2	377.4	2.88	3.32	4.00	4.01

[1] One-third carbonate.

TABLE 5.—*Carbonate content of soils with given resistance*

Soil resistance at 60° F.	Carbonate content of—				Soil resistance at 60° F.	Carbonate content of—			
	Sand	Loam	Clay loam	Clay		Sand	Loam	Clay loam	Clay
Ohms	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Ohms*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
24	3.00	--------	--------	--------	130	0.41	0.53	0.59	0.72
25	2.90	3.00	3.00	--------	135	.39	.51	.57	.69
30	2.10	2.22	2.22	3.00	140	.38	.49	.55	.66
35	1.64	1.91	1.91	2.55	145	.37	.47	.53	.63
40	1.42	1.72	1.74	2.28	150	.36	.45	.51	.61
45	1.24	1.54	1.56	2.05	155	.35	.44	.50	.59
50	1.12	1.40	1.42	1.87	160	.34	.43	.49	.56
55	1.00	1.27	1.29	1.72	165	.33	.41	.47	.54
60	.87	1.16	1.18	1.60	170	.32	.40	.46	.52
65	.80	1.06	1.08	1.48	175	.31	.39	.45	.51
70	.74	.98	1.00	1.38	180	.31	.38	.44	.49
75	.68	.92	.95	1.29	185	.30	.37	.43	.47
80	.64	.86	.90	1.22	190	.30	.36	.42	.46
85	.59	.81	.86	1.14	195	.29	.35	.41	.45
90	.56	.77	.82	1.08	200	.29	.34	.40	.43
95	.54	.73	.79	1.01	210	.26	.32	.38	.39
100	.51	.69	.75	.97	220	.24	.31	.37	.36
105	.49	.65	.72	.91	240	.21	.28	.34	.33
110	.47	.63	.69	.87	260	.19	.26	.32	.31
115	.45	.60	.66	.83	300	--------	.22	.28	.29
120	.43	.57	.64	.79	340	--------	.18	.23	.24
125	.42	.55	.61	.75	380	--------	--------	.20	.20

STANDARDIZING AN AREA

If more than ordinarily accurate work is required or if the tables given do not suit the conditions of an area, a special standard curve may be made of the salt accumulation in the soils of an area, as follows: Eight or ten salt crusts, so selected as to represent comprehensively and typically the conditions in the area, are collected and mixed. Of this mixture several hundred grams are taken, and about twice the volume of water is added. After this has been thoroughly stirred and filtered, 100 c c. of the solution is evaporated to dryness in a weighed vessel. The residue is gently ignited to remove the water of crystallization and the organic matter. The vessel is reweighed after it has been cooled, and the gain in weight in grams is the percentage of salt in the solution. This residue, or the original solution, may be treated for carbonates for the purpose indicated below. If the solution is stronger than 3 per cent, it should be diluted to that strength; if weaker, it should be concentrated to approximately 3 per cent. To dilute too concentrated a solution, the approximate percentage of salt present is first determined; this value, divided by 3 and multiplied by 100, will give the volume to which 100 c. c. of the solution should be diluted in order to give a 3 per cent solution. For example, if the solution has a salt content of 4.7 per cent, the volume to which 100 c. c. should be diluted is equal to $\frac{4.7}{3} \times 100$ or 156.6 c. c.; so that by adding 56.6 c. c. of water to 100 c. c. of the solution, the desired concentration of 3 per cent is obtained. If it is necessary to concentrate the solution, the exact salt content of 100 c. c. of the solution should be determined after concentration, in the manner already described. and the necessary dilution of the main solution be made to give a 3 per cent salt content. When a 3 per cent solution has been obtained, the electrical resistance is measured.

By systematic dilution, solutions of 1.00, 0.60, 0.40, and 0.20 per cent are prepared, and the resistance of each is determined. These dilutions may be made as follows: Take 33.3 c. c. of a 3 per cent solution and dilute it to 100 c. c. for a 1 per cent solution; take 60 c. c. of a 1 per cent solution and dilute it to 100 c. c. for a 0.60 per cent solution; take 66.7 c. c. of a 0.60 per cent solution and dilute it to 100 c c. for a 0.40 per cent solution; and take 50 c. c. of a 0.40 per cent solution and dilute it to 100 c. c. for a 0.20 per cent solution. If the residues, when treated for carbonates by the addition of hydrochloric acid. give little or no evidence that carbonates are present, Table 2 may be used. Multiplying the resistance of a solution reduced to 60° F. by the corresponding ratio for a particular soil class will give the resistance of the wet-soil material, and from the table the corresponding percentage of salt in the dry soil may be determined. From these values the special curve is constructed, whose ordinates and abscissas are the percentage composition of salt and the resistance in ohms, respectively.

It will generally be found advisable not to attempt to construct a special curve for an area unless the facilities of a laboratory are available. In most cases the chances for error in working out a curve in the field are greater than in accepting the tables already

prepared. Though the operations are simple, the lack of laboratory facilities and the limited training of field men in laboratory technic make it difficult to standardize an area, except where samples can be properly collected and carried to a laboratory for standardization.

If the test for carbonates shows the presence of much of those salts, the ratios of Table 4 should be used. This table is based on a salt content of which one-third is carbonates. For exceptional accuracy, the percentage of carbonate in the salt may be determined and a new ratio proportional to the quantity of carbonate present obtained.

USE OF BRIDGE FOR SOLUTIONS

When the bridge is used for solutions the cup is filled, and the reading is made in the manner already described. After the resistance has been corrected for temperature the parts per million of salt in the solution are determined by the use of Table 6, which is reproduced from a publication by King and Whitson.[2] This method of determining the soluble salt in a solution has been used in the laboratory; and, where great accuracy is not required, its use results in an important saving of time.

TABLE 6.—*Soluble salts in solutions at 60° F.*

Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million
68	3,500	108	59	148	450	188	1,121	228	895	268	731	308	640
69	400	109	9	149	440	189	1,114	229	890	269	728	309	638
70	300	110	19	150	430	190	107	230	885	270	725	310	636
71	250	111	2,000	151	420	191	100	231	880	271	722	311	634
72	200	112	1,981	152	410	192	1093	232	875	272	719	312	632
73	150	113	962	153	400	193	86	233	870	273	716	313	630
74	100	114	943	154	390	194	80	234	865	274	713	314	628
75	50	115	924	155	380	195	74	235	860	275	710	315	626
76	3,000	116	905	156	370	196	68	236	855	276	707	316	624
77	2,950	117	887	157	360	197	62	237	850	277	704	317	622
78	900	118	869	158	350	198	56	238	845	278	701	318	620
79	850	119	851	159	341	199	50	239	840	279	698	319	618
80	800	120	834	160	332	200	44	240	835	280	696	320	616
81	767	121	817	161	324	201	38	241	830	281	694	321	614
82	733	122	800	162	316	202	32	242	825	282	692	322	612
83	700	123	783	163	308	203	26	243	820	283	690	323	610
84	667	124	766	164	300	204	20	244	815	284	688	324	608
85	633	125	749	165	292	205	14	245	810	285	686	325	606
86	600	126	732	166	284	206	8	246	805	286	684	326	604
87	571	127	715	167	276	207	2	247	800	287	682	327	602
88	542	128	1,700	168	268	208	996	248	796	288	680	328	600
89	513	129	685	169	260	209	990	249	792	289	678	329	598
90	484	130	670	170	252	210	985	250	788	290	676	330	596
91	456	131	655	171	244	211	980	251	784	291	674	331	594
92	427	132	640	172	236	212	975	252	780	292	672	332	592
93	400	133	626	173	228	213	970	253	776	293	670	333	590
94	375	134	613	174	220	214	965	254	773	294	668	334	588
95	350	135	600	175	212	215	960	255	770	295	666	335	586
96	325	136	587	176	205	216	955	256	767	296	664	336	584
97	300	137	574	177	198	217	950	257	764	297	662	337	582
98	276	138	562	178	191	218	945	258	761	298	660	338	580
99	253	139	550	179	184	219	940	259	758	299	658	339	578
100	230	140	538	180	177	220	935	260	755	300	656	340	577
101	208	141	527	181	170	221	930	261	752	301	654	341	576
102	186	142	516	182	163	222	925	262	749	302	652	342	575
103	164	143	505	183	156	223	920	263	746	303	650	343	574
104	142	144	494	184	149	224	915	264	743	304	648	344	573
105	121	145	483	185	142	225	910	265	740	305	646	345	572
106	100	146	472	186	135	226	905	266	737	306	644	346	571
107	79	147	461	187	128	227	900	267	734	307	642	347	570

[2] KING, F. H., and WHITSON, A. R. DEVELOPMENT AND DISTRIBUTION OF NITRATES AND OTHER SOLUBLE SALTS IN CULTIVATED SOILS. Wis. Agr. Expt. Sta. Bul. 85, 48 p., illus. 1901.

TABLE 6.—*Soluble salts in solutions at 60° F.*—Continued

Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million	Resistance at 60° F.	Parts per million
348	569	400.8	488	474.6	407	586	326	765	245	1,097	165	2,055	85
349	568	401.6	487	475.8	406	587.5	325	768	244	1,104	164	2,079	84
350	567	402.4	486	477	405	589	324	771	243	1,110	163	2,103	83
351	566	403	485	478	404	591	323	774	242	1,118	162	2,128	82
352	565	403.8	484	479	403	593	322	777	241	1,125	161	2,152	81
353	564	404.6	483	480	402	594.5	321	780	240	1,132	160	2,177	80
354	563	405.4	482	481	401	596	320	783	239	1,140	159	2,203	79
355	562	406.2	481	482	400	598	319	786	238	1,147	158	2,232	78
356	561	407	480	483.2	399	600	318	789	237	1,154	157	2,259	77
357	560	407.8	479	484.4	398	601.5	317	792	236	1,161	156	2,288	76
358	559	408.6	478	485.6	397	603	316	795	235	1,168	155	2,320	75
359	558	409.4	477	486.8	396	605	315	798	234	1,176	154	2,351	74
360	557	410.2	476	488	395	607	314	801	233	1,184	153	2,383	73
361	556	411	475	489.2	394	609	313	804	232	1,192	152	2,416	72
362	555	411.8	474	490.4	393	611	312	807	231	1,200	151	2,451	71
363	554	412.6	473	491.6	392	612.5	311	811	230	1,208	150	2,486	70
364	553	413.4	472	492.8	391	614	310	814	229	1,216	149	2,522	69
364.5	552	414.2	471	494	390	616	309	817	228	1,224	148	2,555	68
365	551	415	470	495	389	618	308	820	227	1,232	147	2,593	67
365.5	550	415.8	469	496	388	620	307	824	226	1,240	146	2,631	66
366	549	416.6	468	497.5	387	622	306	827	225	1,248	145	2,670	65
366.5	548	417.4	467	499	386	624	305	830	224	1,257	144	2,712	64
367	547	418.2	466	500.5	385	626	304	834	223	1,265	143	2,755	63
367.5	546	419	465	502	384	628	303	837	222	1,274	142	2,798	62
368	545	420	464	503	383	630	302	841	221	1,283	141	2,842	61
368.5	544	421.0	463	504	382	632	301	844	220	1,292	140	2,886	60
369	543	422.0	462	505.5	381	634	300	848	219	1,301	139	2,932	59
369.5	542	423.0	461	507	380	636	299	851	218	1,310	138	2,978	58
370	541	424	460	508	379	638	298	854	217	1,320	137	3,025	57
370.5	540	424.8	459	509	378	640	297	858	216	1,328	136	3,071	56
371	539	425.6	458	510.5	377	642	296	862	215	1,337	135	3,120	55
371.5	538	426.4	457	512	376	644	295	865	214	1,346	134	3,170	54
372	537	427.2	456	513	375	646	294	869	213	1,355	133	3,220	53
372.5	536	428.0	455	514	374	648	293	872	212	1,365	132	3,277	52
373	535	429.0	454	515.5	373	650	292	876	211	1,374	131	3,336	51
373.5	534	430.0	453	517	372	652	291	880	210	1,384	130	3,394	50
374	533	431.0	452	518.5	371	654	290	884	209	1,394	129	3,450	49
374.5	532	432.0	451	520	370	656	289	887	208	1,404	128	3,508	48
375	531	433	450	521	369	658	288	891	207	1,414	127	3,576	47
375.5	530	433.8	449	522	368	661.5	287	895	206	1,423	126	3,648	46
376	529	434.6	448	523.5	367	663	286	899	205	1,433	125	3,717	45
376.5	528	435.4	447	525	366	665	285	903	204	1,443	124	3,788	44
377	527	436.2	446	526	365	667	284	907	203	1,453	123	3,858	43
377.5	526	437	445	527	364	669.5	283	911	202	1,464	122	3,935	42
378	525	438.0	444	528.5	363	672	282	915	201	1,475	121	4,005	41
378.5	524	439.0	443	530	362	674	281	920	200	1,486	120	4,090	40
379	523	440.0	442	531.5	361	676	280	924	199	1,498	119	4,180	39
379.5	522	441.0	441	533	360	678.5	279	928	198	1,509	118	4,275	38
380	521	442	440	534.5	359	681	278	932	197	1,520	117	4,375	37
380.5	520	442.8	439	536	358	683	277	936	196	1,533	116	4,475	36
381	519	443.6	438	537.5	357	685	276	940	195	1,546	115	4,580	35
381.5	518	444.4	437	539	356	687.5	275	944	194	1,559	114	4,695	34
382	517	445.2	436	540.5	355	690	274	948	193	1,572	113	4,810	33
382.5	516	446	435	542	354	692.5	273	953	192	1,585	112	4,925	32
383	515	447	434	543.5	353	695	272	958	191	1,599	111	5,050	31
383.5	514	448	433	545	352	697.5	271	962	190	1,614	110	5,195	30
384	513	449	432	546.5	351	700	270	966	189	1,629	109	5,340	29
384.5	512	450	431	548	350	702	269	971	188	1,645	108	5,500	28
385	511	451	430	549.5	349	704	268	976	187	1,661	107	5,660	27
386	510	452	429	551	348	707	267	981	186	1,678	106	5,820	26
386.5	509	453	428	552.5	347	709	266	985	185	1,695	105	6,020	25
387	508	454	427	554	346	712	265	990	184	1,712	104	6,260	24
387.5	507	455	426	555.5	345	715	264	995	183	1,729	103	6,560	23
388	506	456	425	557	344	717	263	1,000	182	1,746	102	6,980	22
389	505	457	424	558.5	343	720	262	1,005	181	1,763	101	7,240	21
390	504	458	423	560	342	722	261	1,010	180	1,780	100	7,600	20
390.5	503	459	422	561.5	341	725	260	1,016	179	1,797	99	7,900	19
391	502	460	421	563	340	727	259	1,022	178	1,814	98	8,250	18
391.5	501	461	420	565	339	730	258	1,027	177	1,831	97	8,800	17
392	500	462	419	567	338	732	257	1,032	176	1,848	96	9,300	16
392.5	499	463	418	568.5	337	735	256	1,038	175	1,865	95	9,700	15.5
393	498	464	417	570	336	738	255	1,044	174	1,882	94	10,087	15
393.5	497	465	416	571.5	335	740	254	1,049	173	1,900	93	10,200	14.9
394	496	466	415	573	334	743	253	1,055	172	1,918	92	--------	------
394.5	495	467	414	574.5	333	746	252	1,060	171	1,936	91	--------	------
395	494	468	413	576	332	749	251	1,067	170	1,954	90	--------	------
396	493	469	412	578	331	751	250	1,073	169	1,972	89		
397	492	470	411	580	330	754	249	1,079	168	1,991	88		
398	491	471	410	581.5	329	757	248	1,085	167	2,011	87		
399	490	472.2	409	583	328	760	247	1,091	166	2,033	86		
400	489	473.4	408	584.5	327	762	246						

If for any reason it is suspected that the table does not give accurate results, a new curve can be constructed as follows: A solution is prepared in the same manner as was described in connection with the standardizing of a soil area. Evaporate about 2 liters of the solution to a small bulk. Fill the cup and read the resistance on the bridge. Evaporate in a weighed dish 100 c. c. of the solution, and gently ignite it. Reweigh the dish after it has cooled; the gain in weight gives the quantity of salt in 100 c. c. of the solution. Every centigram increase in weight means 100 parts of soluble salts in 1,000,000 parts, or 0.01 per cent of salt in the solution. By successive dilutions a table or curve may be constructed. One may use 9 parts of the solution and 1 of water; then 8 of the solution and 2 of water, etc. This may be done by taking 90 c. c. and adding 10 c. c. of water, etc. After each dilution the resistance is determined; and by plotting a curve with resistance and parts per million as the coordinates, any intermediate point may be interpolated. With concentrated solutions it is difficult to obtain a minimum on the bridge by the use of the resistance coils alone. In such case the cup coil may be thrown in and a minimum obtained in the manner already described.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

June 30, 1927

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